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3 **GRAVITY-ACTUATED SUBMARINE ANTENNA**

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5 **STATEMENT OF GOVERNMENT INTEREST**

6 The invention described herein may be manufactured and used  
7 by or for the Government of the United States of America for  
8 governmental purposes without the payment of any royalties  
9 thereon or therefor.

10  
11 **BACKGROUND OF THE INVENTION**

12 **(1) Field of the Invention**

13 The present invention relates to antennas and more  
14 particularly to radiators for low profile, towed antennas.

15 **(2) Description of the Prior Art**

16 Present submarine communications with battlegroups or shore  
17 sites utilize surface antennas for a variety of requirements  
18 including SATCOM, LOS, etc. The use of surface antennas  
19 typically interferes with the covert operation of the submarine.  
20 For example, data exchange or the receipt of commands is  
21 accomplished by using antennas within a mast, which must be  
22 extended whenever transmission or reception is required. For  
23 communications in coastal or littoral areas, raising a mast  
24 renders the submarine vulnerable to visual or radar detection.

1 To mitigate such detection, buoyant cable antennas (BCA) are  
2 often used. However, current BCAs cannot be used effectively  
3 for transmission, due to their extremely low radiation  
4 efficiency.

5 Furthermore, antennas towed on the ocean surface are  
6 subjected to dynamic forces that act to cause the antenna to  
7 pitch, yaw and sometimes roll under varying sea states. These  
8 antenna movements can easily result in transmission and  
9 reception interruption, especially so with the use of  
10 directional antennas. As a result, the towing submarine must  
11 operate in a station keeping status or must constantly adjust  
12 course headings in order to obtain optimal antenna performance.

13 In Rivera et al. (U.S. Patent No. 6,127,983), there is  
14 disclosed a wideband antenna capable of transmission and  
15 reception while the antenna is towed horizontally in the ocean  
16 behind the submarine or vessel. Specifically, the antenna of  
17 the cited reference is formed as a metal cylinder having a  
18 longitudinal slot with the longitudinal slot open at one end and  
19 closed at the other end. The cylindrical shape in a towing  
20 container provides a strong righting moment to the antenna with  
21 the result of efficient broadband coverage under varying sea  
22 states.

23 Also, by setting the terminations of the antenna, that is,  
24 the open end, the closed end, and the feedpoint (along with the

1 antenna diameter and thickness, and slot length and width) an  
2 antenna having a good impedance match over a wide frequency band  
3 is produced.

4 As disclosed, the above antenna is clearly suitable for  
5 wideband transmission when being towed in the ocean; however, an  
6 alternative antenna is desirable to produce an increased  
7 effectiveness during operation and an increased range of use  
8 when compared to the above antenna as well as for other known  
9 buoyant antennas.

#### 11 SUMMARY OF THE INVENTION

12 Accordingly, it is a general purpose and primary object of  
13 the present invention to provide an antenna that can transmit a  
14 directionalized radiation pattern with minimal interruption when  
15 operating in varying sea states.

16 It is a further object of the present invention to provide  
17 an antenna in which the antenna construction is simple and  
18 economical.

19 It is a still further object of the present invention to  
20 provide an antenna with an increased antenna gain.

21 It is a still further object of the present invention to  
22 provide an antenna that operates efficiently over a wide band of  
23 frequencies.

1       It is a still further object of the present invention to  
2 provide an antenna in which the operation of the antenna is roll  
3 stable.

4       It is a still further object of the present invention to  
5 provide an antenna that emits a symmetrical radiation pattern in  
6 the fore/aft and athwart directions.

7       To attain the objects described there is provided a  
8 gravity-actuated antenna suitable for towing horizontally on the  
9 ocean surface in which the antenna includes a switching system  
10 that actuates the antenna when facing "up" toward the sky or  
11 ocean surface. The antenna comprises a cylindrical feed tube  
12 with three radially extending fins and disk plates secured to  
13 ends of the feed tube and the fins. A plurality of the curved  
14 plates spaced apart an extending plane of the fins and  
15 projecting from an end plate partially encompass and subtend to  
16 the length of the feed tube with each curved plate connected to  
17 the feed tube by the protecting structure of a gravity-actuated  
18 electrical switch.

19       The fins of the antenna are spaced evenly around the  
20 circumference of the feed tube. Each fin is sized to form a  
21 longitudinal radiation boundary of a resonant cavity and the end  
22 plates are sized to form an athwart radiation boundary of the  
23 resonant cavity with the exterior of the feed tube forming the  
24 base of the resonant cavity. The boundaried resonant cavity is

1 shallow enough that the cavity is not shadowed by the radial  
2 fins and the end plates. Without a shadow condition restricting  
3 a wavelength generated in the resonant cavity during antenna  
4 actuation, a resultant symmetrical radiation pattern can be  
5 transmitted in conjunction with the actuation of a specified  
6 curved plate.

7       The feed tube encompasses a first transmission line from a  
8 feedpoint terminus at one end plate to a cylindrical feed hub  
9 within the feed tube. The transmission line is capable of  
10 conducting radio-frequency energy from the terminus to the hub  
11 and onto an individual electrical switch when the switch is  
12 gravity-actuated as a result of a righting motion of the curved  
13 plates. Energy from the hub via the switch and onto a specified  
14 curved plate and further onto the resonant cavity results in a  
15 current distribution across the curved plate and the resonant  
16 cavity such that a difference in phase between both results in  
17 the radiation pattern beamed from the antenna. Based on the  
18 sizing of the components of the antenna, the resultant radiation  
19 pattern can be transmitted from a fore and aft direction in  
20 relation to the antenna as well as at an athwart direction and  
21 at a direction perpendicular to the axis of the feed tube.

22       By decreasing the diameter of the transmission line from  
23 the feedpoint terminus to the hub, the transmission line  
24 performs an impedance transformation over its length. The

1 impedance transformation of the transmission line among varying  
2 diameters presents a variable load ( $\Omega$ ) at the feedpoint terminus  
3 thereby allowing the antenna to emit over a range of  
4 frequencies.

5 A second transmission line with a diameter equal to the  
6 smallest diameter of the first transmission line and  
7 electrically connectable to the hub, continues from the hub onto  
8 a second terminus at the other end plate. The second  
9 transmission line and the second terminus behave as a reactive  
10 impedance to match the impedance at the connection of a pin of  
11 the switch and the hub. By matching the impedance, an optimum  
12 amount of radio-frequency energy can be transferred onto the  
13 actuated switch and curved plate with a result in increased gain  
14 of the antenna.

15 The above and other features of the invention, including  
16 various and novel details of construction and combinations of  
17 parts will now be more particularly described with reference to  
18 the accompanying drawings and pointed out in the claims. It  
19 will be understood that the particular devices embodying the  
20 invention are shown by way of illustration only and not as the  
21 limitations of the invention. The principles and features of  
22 this invention may be employed in various and numerous  
23 embodiments without departing from the scope of the invention.

1                   **BRIEF DESCRIPTION OF THE DRAWINGS**

2           A more complete understanding of the invention and many of  
3 the attendant advantages thereto will be readily appreciated as  
4 the same becomes better understood by reference to the following  
5 detailed description when considered in conjunction with the  
6 accompanying drawings wherein:

7           FIG. 1 is a perspective view of the gravity-actuated  
8 antenna of the present invention showing the physical  
9 configuration of the antenna;

10          FIG. 2 is an alternate perspective view of the antenna of  
11 the present invention with the view taken from reference line 2-  
12 2 of FIG. 1;

13          FIG. 3 is a cross-sectional view of the antenna of the  
14 present invention with a curved plate of the antenna removed for  
15 a clarified view of the electrical transmission structure of the  
16 antenna with the view taken from reference line 3-3 of FIG. 2;

17          FIG. 4 is an end view of the antenna of the present  
18 invention with a curved plate, the feed tube and the radial fins  
19 of the antenna removed and with the view inverted for a  
20 clarified view of the electrical switch configuration of the  
21 antenna with the view taken from reference line 4-4 of FIG. 2;

22          FIG. 5 is a cross-sectional view of the conductive  
23 relationship of the feed hub to the electrical switches of the

1 antenna of the present invention with the view taken from  
2 reference line 5-5 of FIG. 4;

3 FIG. 6 is a three-dimensional view of a radiation pattern  
4 formed by the antenna of the present invention;

5 FIG. 7 is a cross-sectional view of a first variant of the  
6 electrical switch of the antenna of the present invention; and

7 FIG. 8 is a cross-sectional view of a second variant of the  
8 electrical switch of the antenna of the present invention.

9

#### 10 **DESCRIPTION OF THE PREFERRED EMBODIMENT**

11 Referring now to the drawings wherein like numerals refer  
12 to like elements throughout the several views, one sees that  
13 FIG. 1 depicts the gravity-actuated submarine antenna 10 of the  
14 present invention. The antenna 10 is preferably cast with a  
15 rigid thickness from aluminum with brass electrically conductive  
16 components attached. Other commonly acquired materials or  
17 methods known to those skilled in the art may be used in forming  
18 the antenna 10. Such a variant in antenna formation would be  
19 molding the antenna 10 from plastic and plating the antenna with  
20 a conductive material. Another non-exclusive variant in antenna  
21 formation would be molding the antenna 10 from conductive  
22 material.

23 The simplified structure of the antenna 10 generally  
24 comprises a cylindrical feed tube 12 with radially extending



1 fins 14 and disk plates 16, 18 secured to ends of the feed tube  
2 12 and the fins 14. A plurality of curved metal plates 20  
3 spaced apart from the fins 14 and projecting from the end plate  
4 16 partially encompass the length of the feed tube 12 with each  
5 curved plate 20 connected to the feed tube 12 by a flange 21 and  
6 the protective structure of an electrical switch 22.

7 Each curved plate 20 of the antenna 10 projects at a  
8 distance (A) of  $\lambda/3$  from the end plate 16, wherein  $\lambda$  is the  
9 wavelength corresponding to the center design frequency. The  
10 center design frequency is the geometric mean frequency between  
11 the frequencies provided to the antenna 10. Each curved plate  
12 20 subtends to the feed tube 12 at an angle in the range of  $45^\circ$   
13 to  $90^\circ$ , with the high end of the range preferred for broadened  
14 antenna bandwidth.

15 The radial fins 14 of the antenna 10 are spaced at  $120^\circ$   
16 from each other around the circumference of the feed tube 12.  
17 Each radial fin 14 is sized to form a longitudinal radiation  
18 boundary of a resonant cavity 23 (a volume shown) with the  
19 dimensions of each radial fin 14 at  $\lambda/22$  in width (B) and  $2 \times$   
20  $\lambda/5$  in length (C). The end plates 16, 18 are sized to form an  
21 athwart radiation boundary of the resonant cavity 23 with the  
22 diameter of each of the end plates 16, 18 sized to be  $\lambda/8$ . An  
23 exterior of the feed tube 12 forms the base of the resonant  
24 cavity 23.

1       The boundaried resonant cavity 23 is shallow enough that  
2   the cavity is not shadowed by the radial fins 14 nor the end  
3   plates 16, 18. Without a shadow condition restricting a  
4   wavelength generated in the resonant cavity 23 during actuation  
5   of the antenna 10, a resultant symmetrical radiation pattern 24  
6   can be transmitted in conjunction with the actuation of a  
7   specified curved plate 20. As discussed below for FIG. 6, the  
8   resultant radiation pattern 24 can be transmitted from a fore  
9   and aft direction as well as at an athwart direction and at a  
10   direction perpendicular to the axis of the feed tube 12.

11       The end plate 16 further includes a stub terminus 25 to the  
12   feed tube 12 through a central portion of the end plate 16 and  
13   as shown in FIG. 2, the end plate 18 includes a feedpoint  
14   terminus 26 to the feed tube 12 through a central portion of the  
15   end plate 18. The terminus 26 and the terminus 25 are  
16   respectfully at the ends of the coaxial transmission lines 30  
17   and 32 shown in FIG. 3.

18       As shown in the cross-sectional view of FIG. 3, the feed  
19   tube 12 encompasses and protects the transmission line 30 with  
20   the transmission line 30 continuing from the terminus 26 to a  
21   cylindrical feed hub 34. The diameter of the feed tube 12 is  
22   sized to contain the transmission lines 30 and 32 without  
23   impacting the impedance seen at the hub 34 such that the  
24   diameter of the feed tube is slightly larger than the hub 34.

1       The transmission line 30 is capable of conducting radio-  
2 frequency energy from the terminus 26 to the hub 34 and onto an  
3 individual electrical switch 22 when the switch 22 is actuated  
4 by the electrical connection of the hub 34 to the switch 22 (the  
5 connection of conducting wire 36 within the switch 22 is shown  
6 in FIG. 5, FIG. 7 and FIG. 8). Energy from the switch 22 and  
7 onto a specified curved plate 20 and outward to the resonant  
8 cavity 23 results in the radiation pattern 24 of the antenna 10.

9       By decreasing the diameter of the transmission line 30 in a  
10 stepwise or tapered manner, the transmission line 30 performs an  
11 impedance transformation over its length. The impedance  
12 transformation of the transmission line 30 among varying  
13 diameters presents a variable load ( $\Omega$ ) at the terminus 26  
14 thereby allowing the antenna 10 to emit over a range of  
15 frequencies. Because the switch 22 and the curved plate 20  
16 would each have a unique impedance based on their structure and  
17 size, the degree of tapering of the transmission line 30 (or  
18 lack thereof) also depends on the dimensions of the switch 22  
19 and the curved plate 20.

20       As further shown in FIG. 3, the second transmission line 32  
21 has a diameter equal to the smallest diameter of the  
22 transmission line 30. The second transmission line 32 is  
23 electrically connectable to the hub 34 and continues from the  
24 hub 34 onto the terminus 25 such that the transmission line 32

1 and the terminus 25 behave as a short-circuit electrically in  
2 parallel with the connection of a pin 38 of the switch 22 and  
3 the hub 34. The length and the diameter of the transmission  
4 line 32 determines the amount of reactive impedance of the  
5 transmission 32 to match the impedance at the connection of the  
6 pin 38 and the hub 34. By matching the impedance, an optimum  
7 and undistorted amount of radio-frequency energy can be  
8 transferred onto the actuated switch 22 and curved plate 20 with  
9 a result in increased gain of the antenna 10.

10 As shown in FIG. 4, the antenna 10 preferably includes  
11 three switches 22 positioned equidistant along the circumference  
12 of the feed tube 12 with the attached curved plates 20 also  
13 positioned equidistant. Since three curved plates 20 are  
14 attached, the chord width (D) of the curved plate 20 can be  
15 maximized to enhance a angular range of a righting or "facing  
16 up" action that mechanically actuates the switch 22. By  
17 maintaining the righting action of the actuated switch 22 over a  
18 widened range, the operation of the antenna 10 thereby becomes  
19 roll-stable during towing. Additionally, the maximum chord  
20 width (D) of the curved plate 20 permits a greater bandwidth to  
21 be emitted from the antenna 10. Because the attachment point of  
22 the switch 22 to the curved plate 20 also affects the impedance  
23 bandwidth of the antenna 10, the preferred attachment point 42  
24 is  $\lambda/6$  from the open edge 44.

1        A cross-sectional view of the electrical switch 22 of the  
2 antenna 10 used for the actuation described below is shown in  
3 FIG. 5; however, other suitable variations of the switch 22 are  
4 described for FIG. 7 and FIG. 8. As stated above, the  
5 dimensions of the switch 22, specifically its supporting  
6 structure, can affect the impedance seen at the terminus 26. As  
7 such, the desired diameter (E) of the switch 22 is  $\lambda/45$  and the  
8 desired height (F) of the switch 22 is  $\lambda/22$ . The conical taper  
9 50 of the switch 22 preferably has an angle of  $45^\circ$  and occupies  
10 25% of the switch height(F). While the dimensions of the  
11 supporting structure of the switch 22 are preferred for a center  
12 design frequency over which the antenna 10 maintains a good  
13 impedance match, other supporting structures for the switch 22  
14 such as a cylinder without a taper may be used with compensating  
15 changes in the diameter (E) and the height(F).

16        In the operation of the antenna 10, the feedpoint terminus  
17 26 of the transmission line 30 is connected to a energized feed  
18 source (not shown) at a portion of the UHF spectrum from 240-  
19 270 MHz. The transmission line 30 allows the radio-frequency  
20 energy to be conducted via the hub 34 and onto an electrical  
21 switch 22. The conductive function of the switch 22 is actuated  
22 by gravity whenever the attached curved plate 20 is righted or  
23 faces "upwards" as a result of wave action buoying the curved  
24 plate 20. The attached curved plate 20 is typically able to be

1   righted at an angle greater than  $17^{\circ}$  relative to a horizontal  
2   plane.

3           When the curved plate 20 is righted and the switch 22  
4   inclines, a metal sphere 60 rolls to contact the conducting wire  
5   36, conductive to the structure of the switch 22, with a wire 64  
6   in contact with the pin 38. Energy from the hub 34 via the pin  
7   38 continues to the curved plate 20. The energy to the curved  
8   plate 20 results in a sinusoidal current distribution flowing  
9   along and across a surface 66 of the curved plate 20. The  
10   direction and intensity of the current distribution varies with  
11   the frequency of the antenna 10.

12          When energized, the switch 22 also emits a sinusoidal wave  
13   that sets up a current distribution on a surface 67, 68 of the  
14   fins 14 and a surface 69 of the feed tube 12 in the resonant  
15   cavity 23. The differences in phase from the various radiating  
16   surfaces 66, 67, 68 and 69 contributes to the generally  
17   hemispherical radiation or beam pattern 24, shown in FIG. 6.

18          In FIG. 6, the radiation pattern 24 is depicted as a  
19   mathematical surface known as a horn cyclide (a variant of a  
20   toroid) with a null 72 from the center the horn cyclide to the  
21   lower point 73 of a surface 74. The horn-cyclide shaped  
22   radiation pattern 24 is advantageous because when the antenna 10  
23   is placed on the ocean surface, the radiation pattern 24 in the  
24   air space above the ocean surface (shown by the area 76 above

1 the plane defined by the "x" and "y" coordinates) has a minimal  
2 null area. As such, the radiation pattern 24 in the air space  
3 permits full directionalized transmission allowing the towing  
4 submarine to communicate when is the antenna 10 is subject to  
5 conditions of pitch, yaw, and varying degrees of roll since the  
6 antenna 10 will be righted to the plane defined by the "x" and  
7 "y" coordinates and coincident to the ocean surface.

8        Since the emitting area of the radiation pattern 24 is  
9 symmetrical, problems associated with asymmetrical radiation  
10 patterns are avoided. The symmetrical radiation pattern 24 of  
11 the antenna 10 allows the submarine or ship to operate the  
12 antenna for optimal antenna performance without station keeping  
13 or adjusting course headings.

14        An additional feature of the present invention is that the  
15 structural ratio (identified by the wavelength dimensioning  
16 above) of the various components of the antenna 10 allows the  
17 radiation pattern 24 to remain symmetrical while maintaining the  
18 compactness of the antenna 10. The compactness of the antenna  
19 10 is naturally advantageous for many reasons including  
20 detection minimalization and reduced drag. In defining the  
21 compactness feature, the outer physical boundary of the antenna  
22 10 is based on the size and placement of the end plates 16, 18  
23 and the curved plates 20. For example, each curved plate 20 of  
24 the antenna 10 projects at a distance (A) of  $\lambda/3$  from the end

1 plate 16 with the diameter of the end plates 16, 18 sized to be  
2  $\lambda/8$ , therefore any remaining structure of the antenna 10 would  
3 be within a circumferential boundary created by the above  
4 dimensions. Also, the radial fins 14 of the antenna 10 are 2  
5 times  $\lambda/5$  in length (C) therefore any remaining structure of the  
6 antenna 10 would be within a longitudinal boundary created by  
7 the dimension of the radial fins 14.

8 While the metal sphere 60 shown in FIG. 5 is used in the  
9 actuation of the switch 22 described above, other variations of  
10 electrical contact within the switch 22 may be used. In a first  
11 variant of the switch 22 shown in FIG. 7, the sphere 60 of the  
12 switch 22 is substituted with a metal plunger 80. The use of  
13 the plunger 80 may be preferred in some circumstances since the  
14 shape as well as the size of the plunger 80 can affect the angle  
15 of gravity-actuation.

16 In a second variation of the switch 22 shown in FIG. 8, the  
17 plunger 80 or sphere 60 is substituted with a gravity-actuated  
18 magnet 90. When the curved plate 20 is righted and the switch  
19 22 inclines, the magnet 90 slides to close the normally open  
20 contacts of the reed switch 96. This allows the reed switch 96  
21 to be conductive to the structure of the switch 22 by the  
22 conducting wires 38 and 64. The magnetic material for the switch  
23 22 must have a substantial mass to perform a switch but the  
24 material also must have a stable magnetic field. In order not



1 to affect the magnetic field or impedance properties of the  
2 antenna 10, the switch 22 may be lined with magnetic shielding  
3 foil material 98.

4 Thus by the present invention its objects and advantages  
5 are realized and although preferred embodiments have been  
6 disclosed and described in detail herein, its scope should be  
7 determined by that of the appended claims.